Electrical Power Engineering (2)

Code: EP2207

Lecture: 4 **Tutorial: 4** **Total: 8**

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CONTROL OF VOLTAGE AND REACTIVE POWER

Reactive Power Control

The balance of reactive power is achieved when the generated reactive power by synchronous machines and capacitances is equal to the reactive power of the loads plus the reactive transmission losses

Imbalance in active power causes frequency fluctuations

Imbalance in reactive power causes a deviation of the voltages from the desired values

CONTROL OF VOLTAGE AND REACTIVE POWER

The voltage drops on the lines are normally small

The voltages of different nodes are almost the same and the voltage drop can be neglected

The voltage is controlled by controlling the reactive power

Increasing the reactive power increases the voltage, while increasing the consumed reactive power decrease the voltage

CONTROL OF VOLTAGE AND REACTIVE POWER

The reactive power cannot be transported over long distances in the system, since normally X >> R

Important sources of reactive power are

- Overexcited synchronous machines
- Capacitor banks
- The capacitance of overhead lines and cables

CONTROL OF VOLTAGE AND REACTIVE POWER

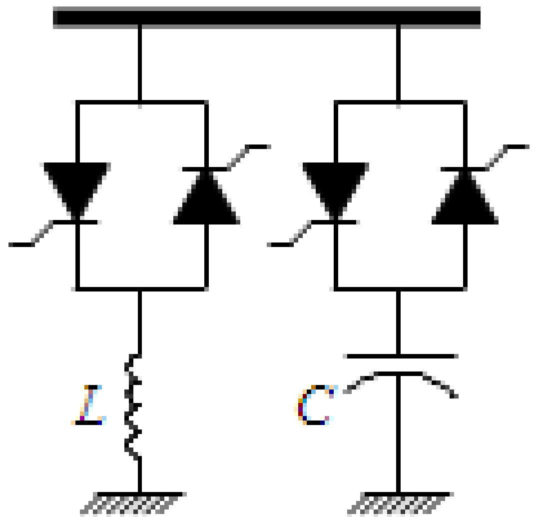
The main consumers of reactive power are:

- Under-excited synchronous machines
- Inductive static loads
- Induction motors
- Shunt reactors
- The inductance of overhead lines and cables
- Transformer inductances
- Line commutated static converters

CONTROL OF VOLTAGE AND REACTIVE POWER

Switching of shunt capacitors and reactors can control the reactive power

If thyristors are used to switch capacitors and/or to control the current through shunt reactors, a fast and step-less control of the reactive power is obtained



Such a device is called SVC (Static Var Compensator)

CONTROL OF VOLTAGE AND REACTIVE POWER

Voltage Control

Factors affecting the selection of power system voltage

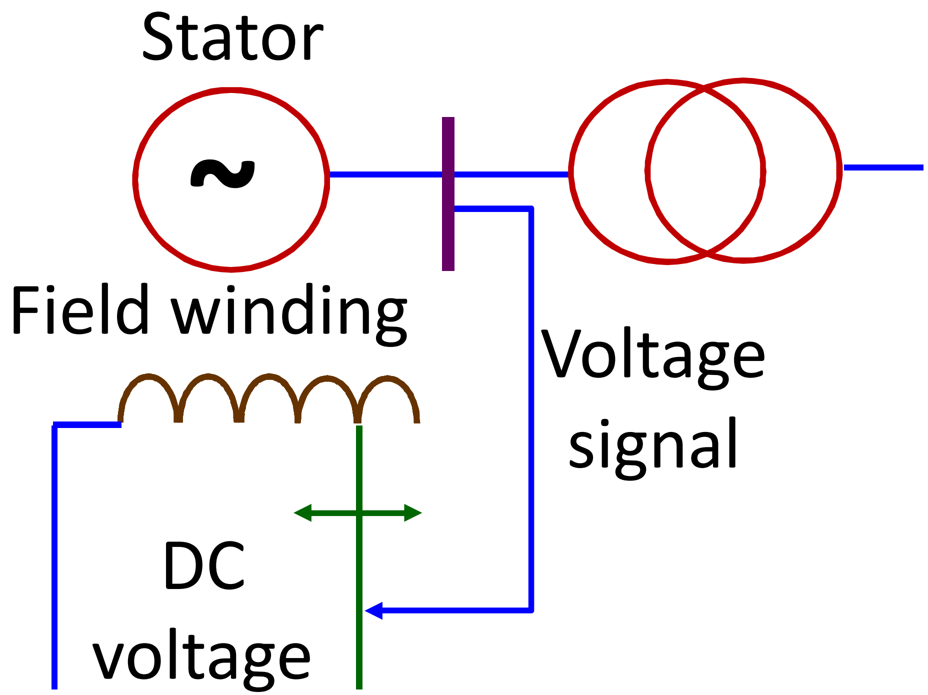
- Terminal voltages of synchronous machines
- Transmitted reactive power
- Impedances of lines
- Turns ratio of transformers

CONTROL OF VOLTAGE AND REACTIVE POWER

The generator voltage can be maintained constant by using an Automatic Voltage Regulator **(AVR)**

The AVR controls the excitation of the machine so that the voltage is kept constant at the set value

This method cannot easily be used for a single generator when a number of generators run in parallel



CONTROL OF VOLTAGE AND REACTIVE POWER

Large reactive transmissions cause large voltage drops, therefore, they should be avoided

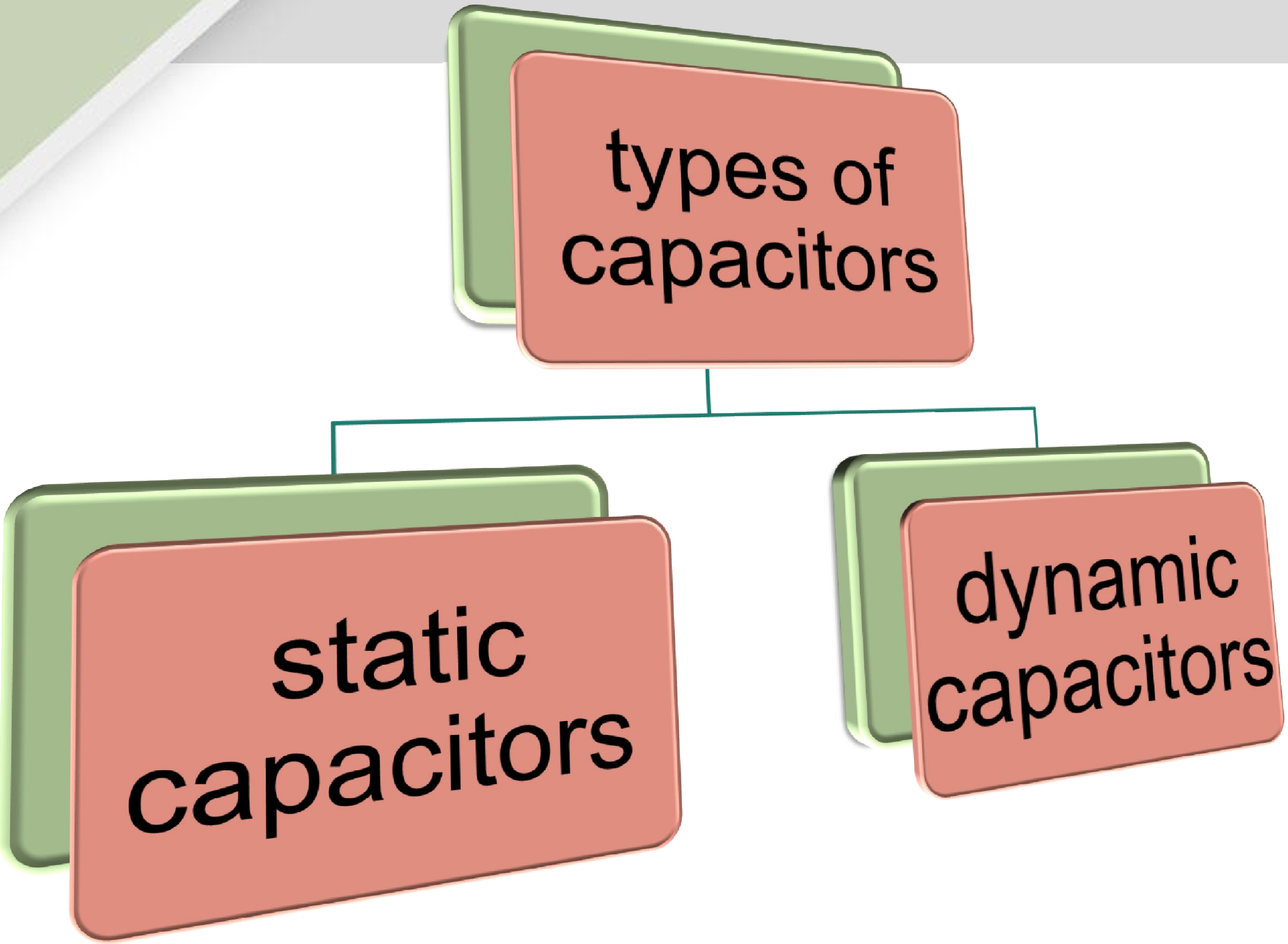
The production of reactive power should be as close as possible to the reactive loads

The most cost-effective way is to use shunt capacitors which are switched according to the load variations

A SVC can be economically motivated if fast response or accuracy in the regulation is required

Shunt reactors must sometimes be installed to limit the voltages to reasonable levels

CONTROL OF VOLTAGE AND REACTIVE POWER



CONTROL OF VOLTAGE AND REACTIVE POWER

dynamic capacitors "synchronous generators”

Synchronous compensators are installed for voltage control

These are synchronous machines without turbine or mechanical load, which can produce and consume reactive power by controlling the excitation

New installations of synchronous compensators are very rare

Instead, capacitors are used at the receiving end of the transmission line to vary the amount of the reactive power

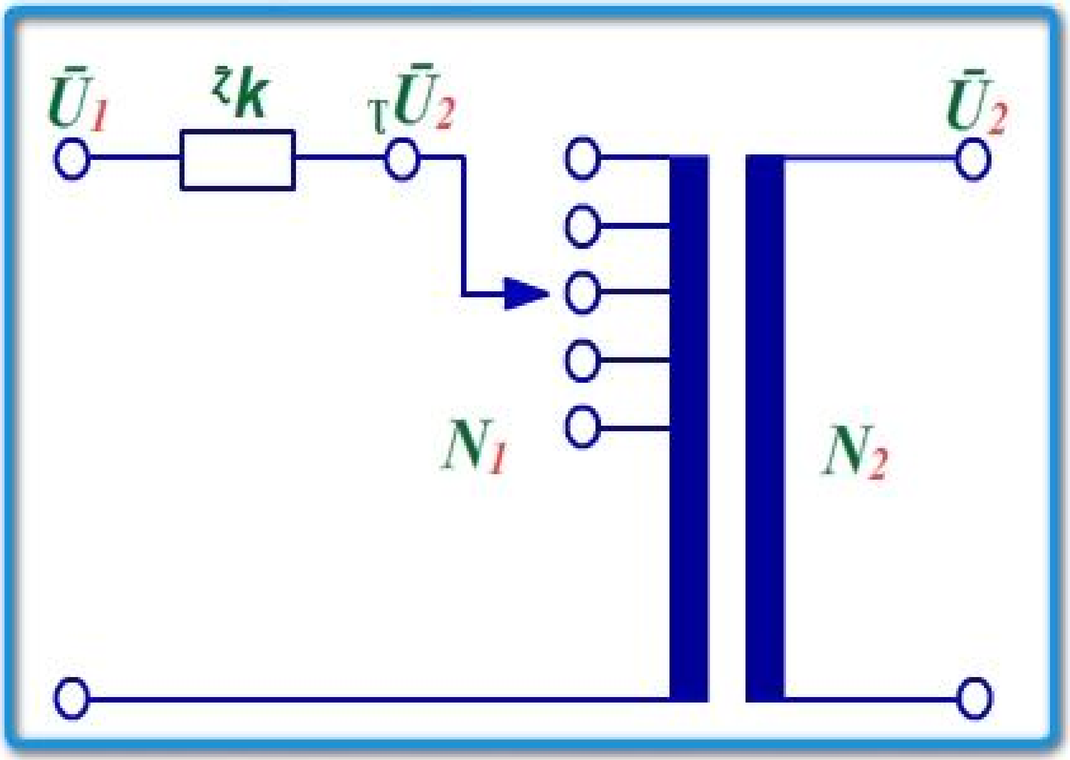
CONTROL OF VOLTAGE AND REACTIVE POWER

Tap- changing transformer

The turns ratio of a transformer is changed to control the voltage in power systems

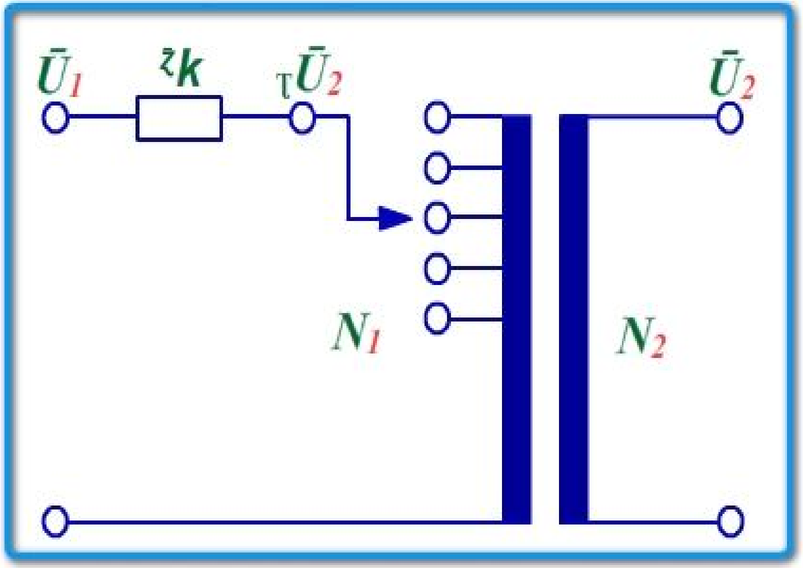
Certain transformers are equipped with a number of taps on the high voltage side

Voltage control can be obtained by switching between these taps



CONTROL OF VOLTAGE AND REACTIVE POWER

Tap- changing transformer



The switching can be done online during operation

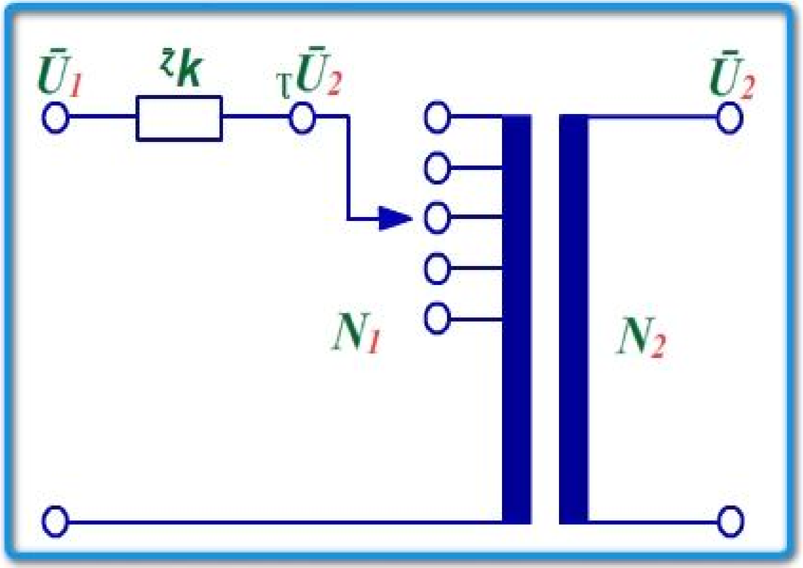
Normally the taps are placed on the high voltage winding, the upper side

The lowest current needs to be switched

The number of turns in the high voltage side is larger, which gives better regulation of the variation ratio

CONTROL OF VOLTAGE AND REACTIVE POWER

Tap- changing transformer



Sometimes, the turns ratio cannot be changed during operation, but when the transformer is off load

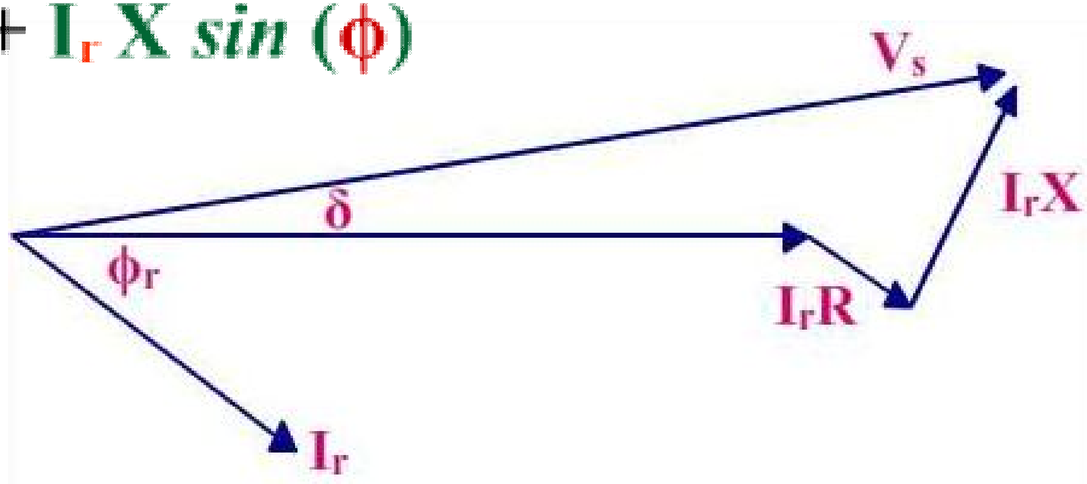
In this case, the voltage level can only be changed in general but the voltage variations in the network are not controlled

The windings used for tap setting are about 10% of the total windings of the transformer

CONTROL OF VOLTAGE AND REACTIVE POWER

Improving the regulation

$$\Delta V = I_r R\, cos\,(\phi) + I_r X\, sin\,(\phi)$$



$$\Delta V = \frac{PR + QX}{V_r}$$

$$Re\, g\% = \frac{\Delta V}{V_r} * 100 = \frac{I_r R\, cos\,(\phi) + I_r X\, sin\,(\phi)}{V_r} * 100$$

$$\Delta V = \frac{PR + QX}{V_r^2} * 100 = \frac{P_r}{V_r^2}\,[R + X\, tan(\phi_r)]$$

CONTROL OF VOLTAGE AND REACTIVE POWER

$$\Delta V = \frac{P_r}{V_r^2}\left[R + x\, tan(\phi_r)\right]$$

To reduce the voltage regulation

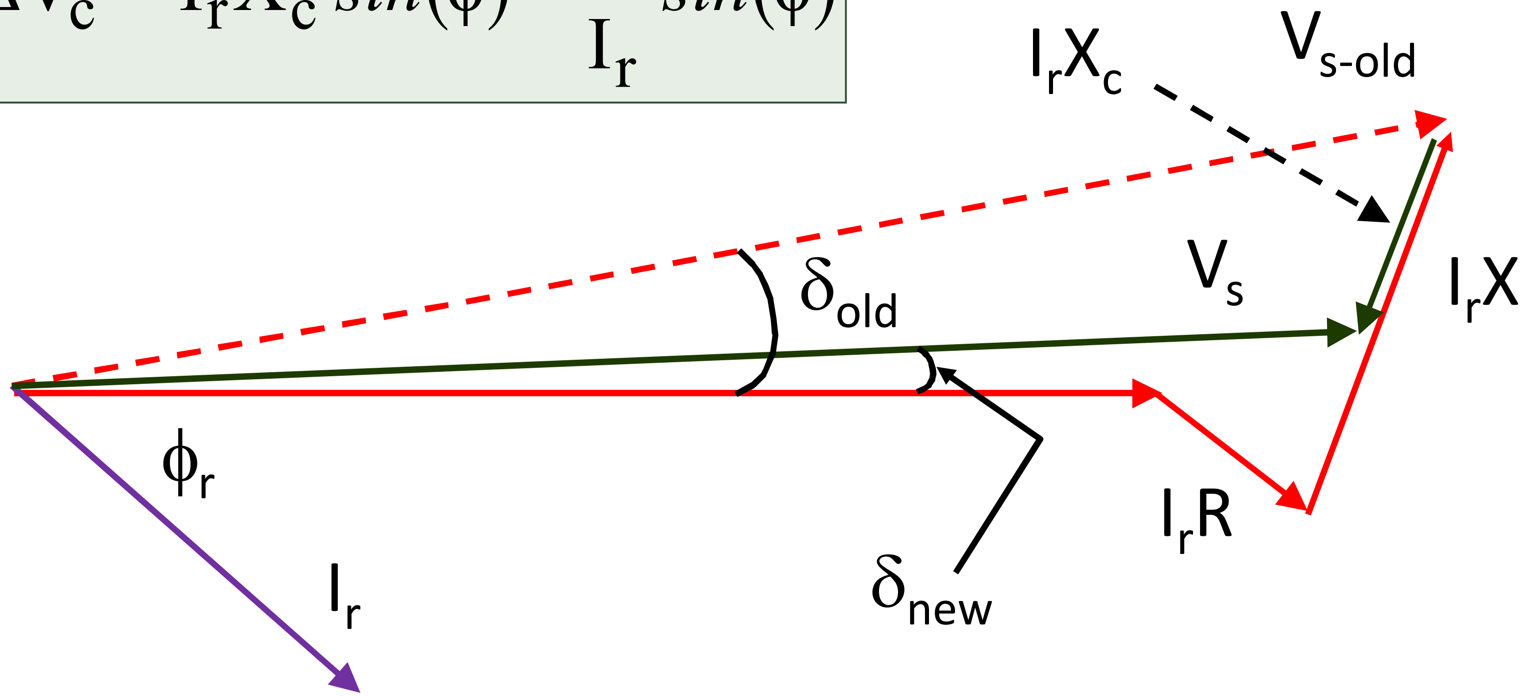
- Increase the operating voltage
- Improve the power factor at the receiving end
- Reduce the resistance of the transmission line, e.g. using double circuit
- Reduce the reactance of TL, e.g. using double circuit, using bundle conductors or using series capacitors

CONTROL OF VOLTAGE AND REACTIVE POWER

With a capacitor used at the receiving end

$$\Delta V = I_r R \, cos(\phi) + I_r X \, sin(\phi) - I_r X_c \, sin(\phi)$$

$$\Delta V_c = I_r X_c \, sin(\phi) = \frac{Q}{I_r} sin(\phi)$$



CONTROL OF VOLTAGE AND REACTIVE POWER

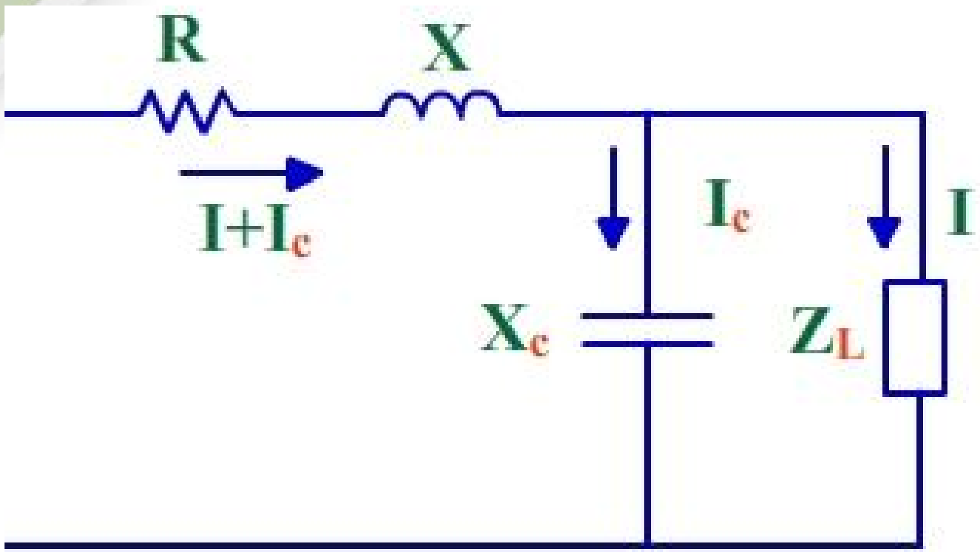
Disadvantages of low power factor

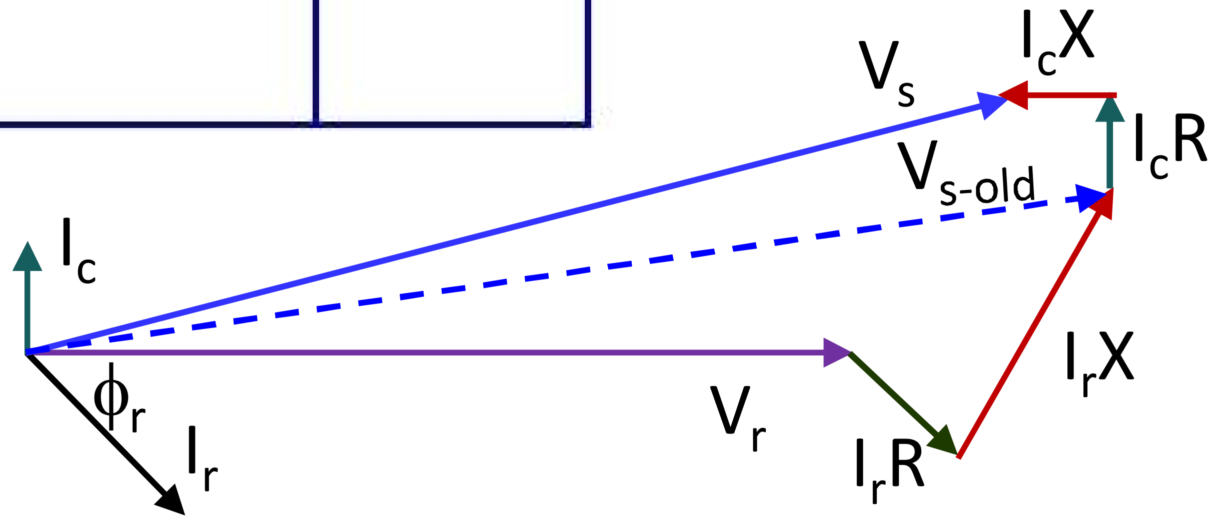
- Higher copper losses
- Poor voltage regulation
- Greater conductor size
- Larger apparent power rating of equipments
- Reduced handling capacity of the system

To improve the power factor, parallel or series capacitors are connected

CONTROL OF VOLTAGE AND REACTIVE POWER

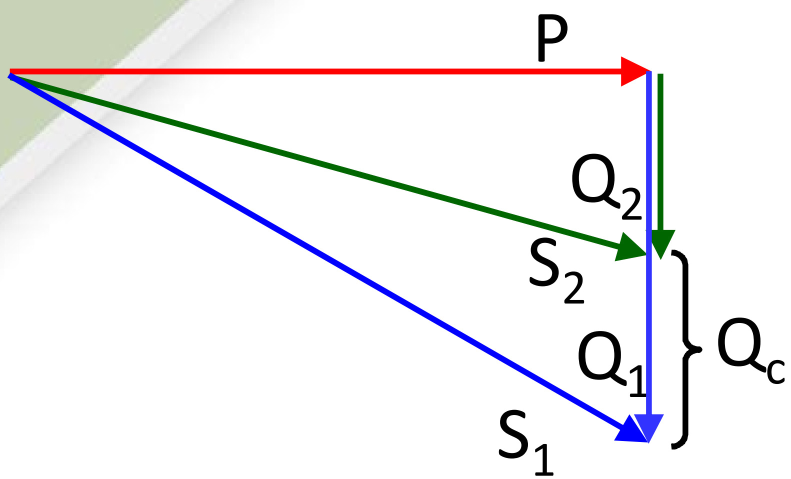
Parallel capacitors

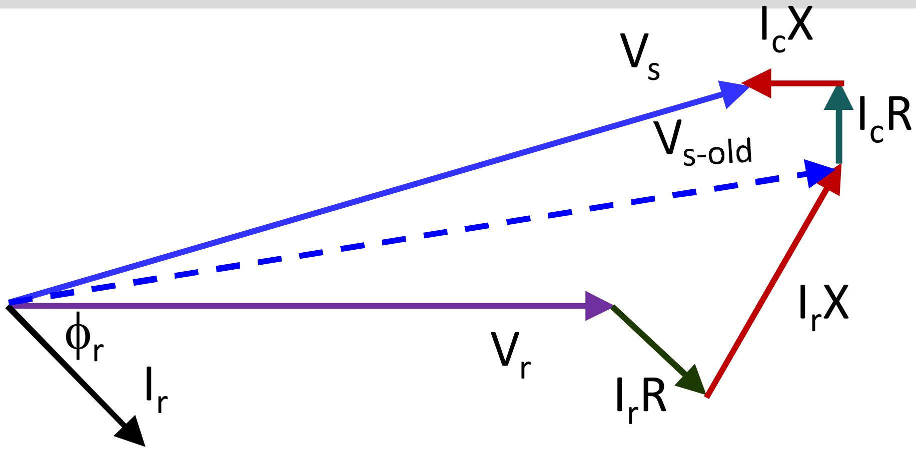




CONTROL OF VOLTAGE AND REACTIVE POWER

Parallel capacitors

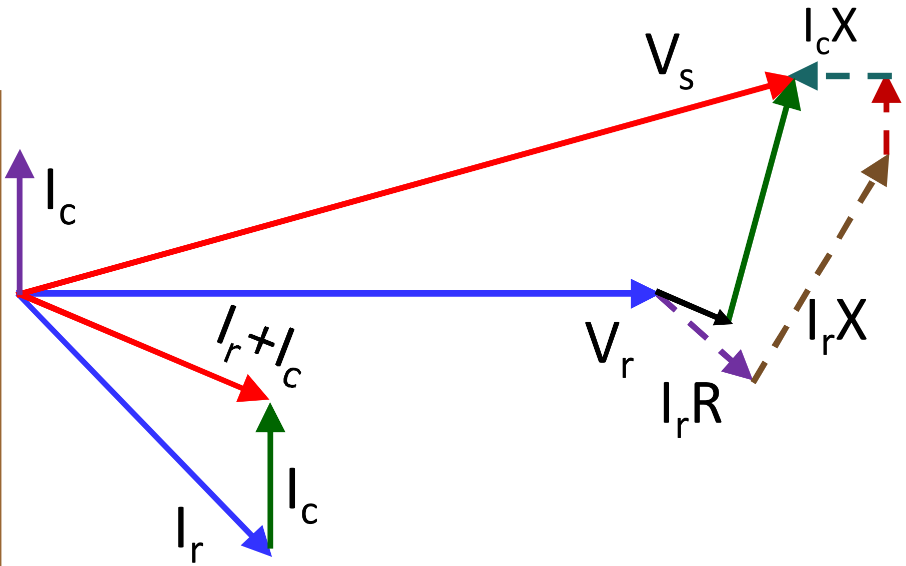




$$\Delta V = I_r R\, cos(\phi) + I_r X\, sin(\phi) - I_c X$$

$$\Delta V_c' = I_c X = \frac{V_r}{X_c} X$$

$$\Delta V_c' = \frac{Q'}{V_r} X$$

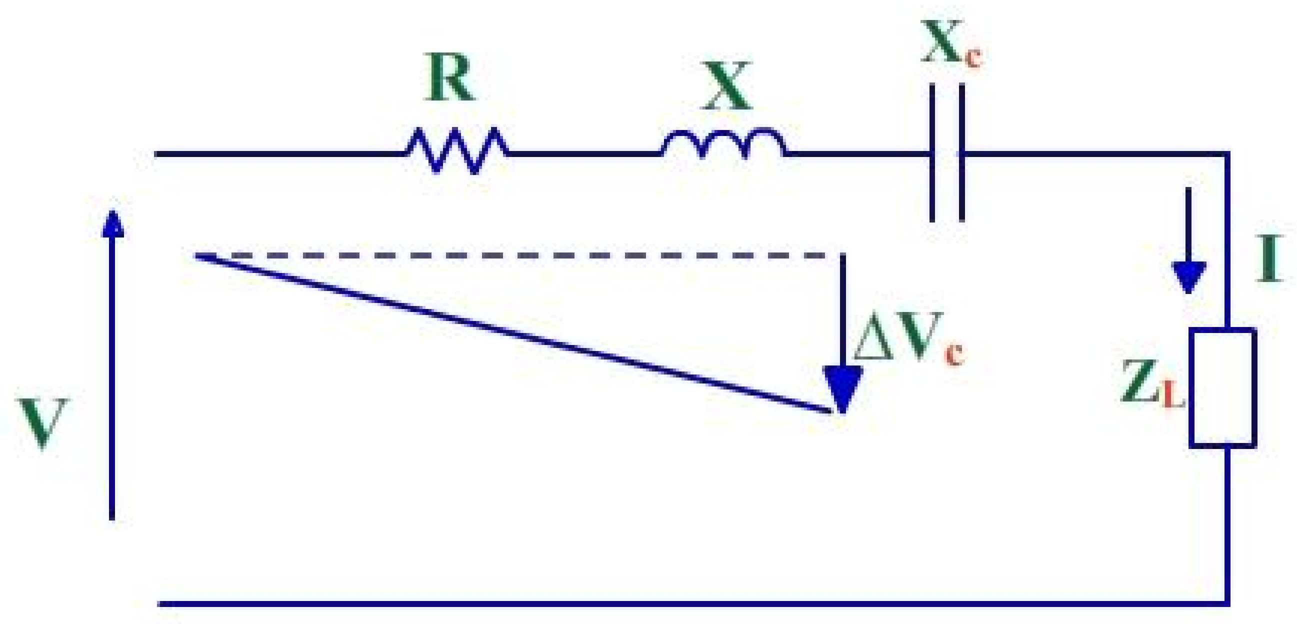


CONTROL OF VOLTAGE AND REACTIVE POWER

Comparison between series and shunt capacitors

In the case of series compensation

$$\Delta V_{c\text{-}s} = \frac{Q}{I} \sin(\phi)$$



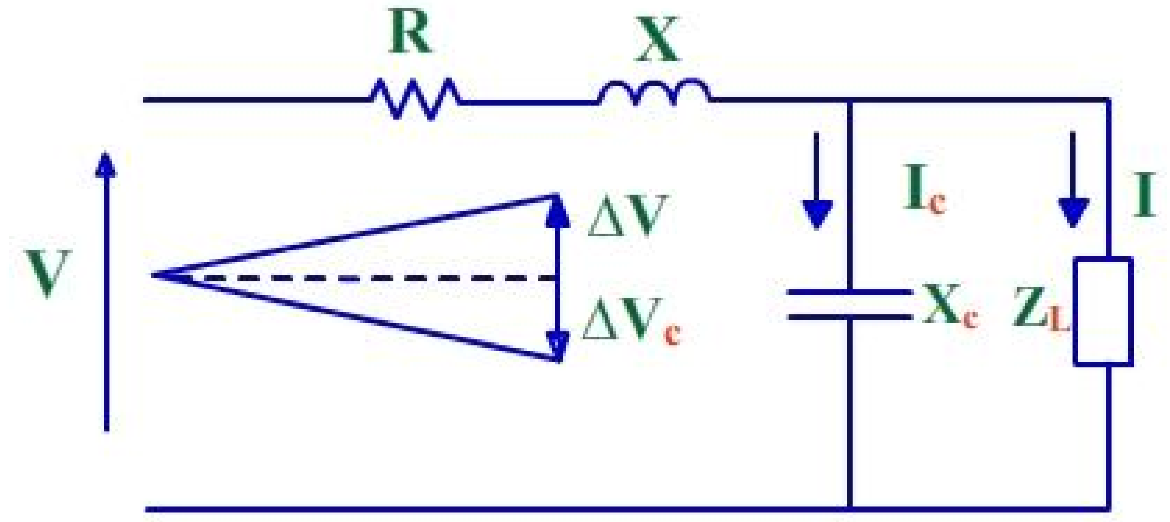
CONTROL OF VOLTAGE AND REACTIVE POWER

Comparison between series and shunt capacitors

Parallel capacitor compensation

In the case of parallel compensation

$$\Delta V_{c\text{-}p} = \frac{Q'}{V_r} X$$



Comparison between series and shunt capacitors

Parallel comparison	Series comparison
• Gradual increase of the voltage	• Sudden increase in the voltage at the capacitor location
• Capacitor is placed on the ground level	• Capacitor has to be placed in on the tower
• Failure of capacitor causes a voltage reduction	• Failure of the capacitor causes a line break

Comparison between series and shunt capacitors

Parallel comparison

- The capacitor current is a part of load current

$$\Delta V_{c-p} = \frac{Q'}{V_r} X$$

Series comparison

- The capacitor current Is the load current

$$\Delta V_{c-s} = \frac{Q}{I} \sin(\phi)$$

CONTROL OF VOLTAGE AND REACTIVE POWER

Comparison between series and shunt capacitors

The ratio between the reactive power obtained from the two capacitors for the same voltage change:

$$\frac{Q'}{V_r} X = \frac{Q}{I} \sin(\phi)$$

$$\frac{Q'}{Q} = \frac{V_r}{IX} \sin(\phi) \approx \frac{V_r * 0.6}{0.1 V_r} \approx 6$$

The reactive power required from the parallel capacitor is equivalent to about six series capacitors

Parallel capacitor is more expensive than series one